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Dynamical influences on the distribution and loading of SO_2

I **:** Middle atmosphere — composition and chemistry; middle atmosphere — constituent transport and chemistry; troposphere — composition and chemistry; troposphere — constituent transport and chemistry.

December 8, 2000; March 16, 2001;**I**

1. I

[2] Sulfate aerosol is of great interest because of its role in scattering solar radiation and modifying the reflectivity of clouds, with possible resultant influence on the Earth's radiation balance and climate [*Charlson et al.* , 1992, 1991; *Haywood et al.* , 1999; *Kiehl and Briegleb* , 1993; *Kiehl et al.* , 2000; *Mitchell et al.* , 1995; *Schimel et al.* , 1996; *Schwartz and Slingo* , 1996]

chemical transport and transformation model

$_2$ that are a consequence of relations between the geographic distribution of sources and of the

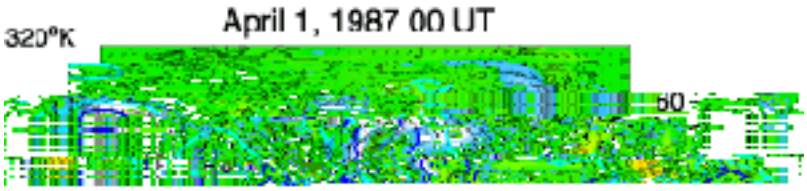
$_2$ column burdens and relates the resulting patterns of these species

k(---Pmr-pnhrc-ds-hCdEry-MB-nMsrCEaidnyhrCdErh-sByn(idg-haia-nMiadyrh-oCnp-ir
ReCn(ray-ryiCr-onC-urhdepayWr-0aimrC-1Crgasis-qRul)-s(rgdodgaccB-imr
2nneC-

, a system of terrain-following coordinates, with 15 levels between the surface and 100 hPa [*ECMWF Research Department* , 1991; *Simmons and Struffing* , 1981]. The model solves material balances based on the continuity equations with the application of *gradient transport assumptions* [*Bott* , 1989; *Easter* , 1993] s

Figure 1. *G* *l* *(SO* *2* *l* *)* *( )* *l* *(DMS* *l* *H* *2* *S)* *.* *T* *l* *DMS* *.* [1, 2] *l* *(CZCS)* *.* *N* *l*

[15] Systems with circulations extending through the depth of the troposphere are capable of accumulating material within their region of influence. Significant events of the anticyclonic or cyclonic type are defined by at least one “closed-contour” at the 500 hPa level, so the climatology of 500 hPa cyclones and anticyclones is an important factor in determining the distribution of material over the hemisphere. The terminology “cutoff low” is typically interchanged with “500 hPa cyclone” because no formal definition distinguishing them has been established. The climatology of anticyclones common than anticyclones. Geographically, 500 hPa cyclones are found primarily at middle and high latitudes, whereas 500 hPa anticyclones are found primarily at


April 1, 1987 00 UT
320°K
60

surface represents conditions in the upper troposphere, whereas that at 295°K represents the lower troposphere. Isentropic analysis is most useful at higher levels of the troposphere where isentropic surfaces are not interrupted by intercepting the ground; it is less useful at lower tropospheric levels where the surfaces intercept the ground in the tropics and in mountainous areas, as indicated by the gray areas on the 295°K, 300°K, and to a lesser extent the 305°K isentropic surfaces.

Figure 4. *Isentropic analysis for April 1 0000 UT at the 295°K, 300°K, 305°K, 310°K, and 320°K surfaces. The potential temperature is constant at all points on each chart, and the*

northern Germany than sulfate. This reflects th

reaction and removal in precipitation.

[23] The minimum in the sulfate column burden corresponds to the three-dimensional parcel trajectories associated with the baroclinic leaf structure and to regions of low sulfate mixing ratio indicated by the white areas in the isentropic surfaces on April 1 0000 UT (Figure 4). Wind vectors off the east coast of the United States show southerly flow, with parcels moving from the 800 hPa isobar off the coast of Florida to the 600 hPa isobar over the Canadian maritime provinces, indicating widespread slantwise ascent. Assuming an average horizontal velocity of 15 m s^{-1} (a typical value for these conditions), for a 1000 km south to north transport the corresponding vertical velocity is approximately -3 ? 10^{-3} hPa s^{-1} (-3 cm s^{-1}, a moderate rate of ascent). A synoptic-scale vertical velocity of this magnitude indicates slow, methodic ascent that will hive rise to widespread precipitation typical of midlatitude cyclones and lead to efficient removal of any sulfate present. Note also that the flow turns sharply west-northwest off the coast of eastern Labrador, so precipitating air parcels moving upward and to the northeast, off the northeast coast of the United States, continue to ascend and may eventually arrive at 400 hPa. At that level the flow is diverted toward the southeast with accompanying precipitation and consequent removal of sulfate.

[24] An example of low sulfur burden in a maritime cutoff low is seen at 50°W and 30°N. The synoptic charts reveal a well-defined cutoff low 400 AlNNbask? to Fiic aq Th,2500 AAdPe cyrientrocgnastruW30°N?a toSJJ,I65C55M9circuid regries associated wikqod cutoff dbe

[24]000atesialW ehese coitime cutoff d5kq?eicatndSJ?9kCNqNA6kA165C55MNobar Irizonty. MeteorPirog vertical,as kqow is Trbap
sic. Ieates,rst cd t that
sic.k? totime cutoff obar Irizontyibasutoffoc?eicateobar aates. ceorizontoying

burden was consid bly lower, most likely owing to the lack of aqueous-phase oxidation caused by the entrainment of dry air from the Middle wI°nmepTflNz°r f~lDn]1°z°nmepTlxi1I°°(F°TIT

flow showed little height gradient

sca

region and production mechani

Figure 5. *Isentropic analysis for April 3 0000 UT. As in*

Fig e . *A 5, 1 7, 6 A 6, 1 7, 6 . F*

Figure 14. *Sulfate column burden on April 5, 1987, 0600 UT and April 6, 1987, 0600 UT. From top to bottom: derived from biogenic sources, derived from North American sources,*

Figure 11.

[44] On April 5 1200 UT, when transport of material from Europe under the influence of the cutoff low had started to affect the study location, the concentration of SO_2 was still largest at ~4 km, and North American sources still predominated at this altitude, but the contribution from European sources was starting to increase at ~1 km. The concentration of sulfate was still largest at the surface, but the contribution from European sources had increased while the contribution of North American sources remained about the same. The predominant formation process for sulfate at all altitudes was still aqueous-phase oxidation.

[45]

are responsible for the transport of material over large distances as well as conditions that can give rise to large column burdens of these materials.

intensification and eastward during dissipation. It prevents the movement of migratory cyclones across its latitudes. Two examples are a cutoff high and an *omega block* .

Column burden: the vertical integral of the concentration of an atmospheric trace species at each vertical level.

Concentration:

approximation can be use in the atmosphere (such as convection) are negligible.

Isentropic analysis:

e: PgPe3 P3e: PPaP a Pgege
gaeP a P3P Paga eg3ePP:eP gPPg3ePaPeP3e 33ePPeg
a3gPag PaPaP:a 3Pa P3Pe3 P:eP P ePg P3P ePg egPe3ege
PaP a gegePgaePPg3eP3P ePag PPaP eP a Pgee:ePa
33a:Pa0eP3P ePe P geaPaP3::PePaPg3ePa3P3P3P eP 3
:P P ePea P3::Pa0ePaPg eg:Pe PaP eP:P P ePe P3::Pa0ePa
eg:Pe P3eP3Peg a3P3ga 3PaPgegee P!3P e

Wind conventions: